

# **Monitoring and Control of the Cardiovascular System During Indoor Exercise**

A thesis written by

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under the supervision of

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## **CERTIFICATE OF AUTHORSHIP/ORIGINALITY**

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.



Kaili Weng

# Abstract

The increase in obesity and diabetes is of great public health, social and economic concern worldwide. Modern treadmill systems can provide effective, safe and practical indoor exercise for the consumption of extra energy. However, an uncontrolled treadmill can cause excessive exertion on the cardiovascular system. To avoid excessive cardiovascular stress, an efficient way of monitoring and controlling of exercise strength is to regulate treadmill speed and/or gradient to stimulate the exerciser's heart rate following a predefined profile.

In this thesis, an automated treadmill system has been developed, which includes wireless portable ECG and tri-axial accelerometer sensors, and a Labview based control module. Based on this automated system, efficient rate detection techniques have been developed by using the pitch estimation method. Different types of multi-loop integral control configurations have been proposed and implemented to regulate the heart rate and/or step rate by manipulating treadmill speed and/or gradient. These control structures have been placed under real time testing which includes Single-Input Single-Output (SISO), Multiple-Input Single-Output (MISO) and Multiple-Input Multiple-Output (MIMO) control by using the established Labview module. It has been found that MISO control is the most efficient method, and would be effective in making the treadmill exercise more reliable and safer in rapidly tracking the heart rate profile to achieve desired exercising outcome. For this reason, this thesis also proposes the concept of Multi-loop Integral Controllability (MIC) and proves the existence of multi-loop integral controllers which can obtain unconditional multi-loop stability of the Two-Input Single-Output automated treadmill system.

The benefit of our automated control system includes assisting patients in post-cardiac attack rehabilitation and therapy to safely control the heart rate to follow a suitable profile. This reduces the need for supervision by medical professionals. Furthermore, in athletics and fitness applications, an automatic control system can allow users to optimize their training intensity.



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# Acronyms and Abbreviations

## Units of Measure

<b>hr</b>	Hour(s)
<b>km/h</b>	Kilometres per hour
<b>min</b>	Minute(s)
<b>m</b>	Meter
<b>sec</b>	Second(s)

## Acronyms

<b>2ISO</b>	Two Inputs and Single Output
<b>ACF</b>	Autocorrelation Function
<b>AMDF</b>	Average Magnitude Difference Function
<b>BPM</b>	Beats Per Minute
<b>DAQ</b>	Data Acquisition
<b>DIC</b>	Decentralized Integral Controllability
<b>DUS</b>	Decentralized Unconditional Stability
<b>ECG</b>	Electrocardiograph
<b>GAS</b>	Globally Asymptotically Stable
<b>GUI</b>	Graphical User Interface
<b>HR</b>	Heart Rate
<b>HRC</b>	Heart Rate Controlled
<b>Kp</b>	Proportional Gain
<b>Ki</b>	Integral Gain
<b>Kd</b>	Derivative Gain
<b>LES</b>	Locally Exponentially Stable
<b>MISO</b>	Multi-Input Single-Output

<b>MIMO</b>	Multi-Input Multi-Output
<b>MIC</b>	Multi-loop Integral Controllability
<b>NI</b>	National Instruments
<b>PC</b>	Personal Computer
<b>PID</b>	Proportional Integral Derivative
<b>PPM</b>	Paces per Minute
<b>RMS</b>	Root Mean Square
<b>SISO</b>	Single-Input Single-Output
<b>SPM</b>	Steps per Minute
<b>SR</b>	Step Rate
<b>TA</b>	Tri-axial Accelerometer
<b>UTS</b>	University of Technology Sydney
<b>VI</b>	Virtual Instrument